

# Radiofrequency ablation of accessory atrioventricular pathways: predictive value of local electrogram characteristics for the identification of successful target sites

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## Abstract

**Background**—Radiofrequency catheter ablation of accessory arterioventricular pathways has been shown to be a highly effective treatment in patients with paroxysmal supraventricular tachycardia. There is, however, considerable variability in the number of attempted ablation sites, contributing to lengthy operations in some cases. The purpose of this study was to investigate the predictive value of local electrogram characteristics for the identification of successful target sites.

**Methods and results**—Local bipolar electrograms from 60 patients recorded at 568 sites of attempted ablation were analysed. There were 511 sites at which ablation was guided by antegrade mapping, with 49 successful sites and 462 failed sites including 61 at which accessory pathway conduction was blocked temporarily. In multivariate analysis, the time of local ventricular activation relative to onset of the QRS complex (QRS-V interval) ( $p < 0.001$ ) and the presence of a possible accessory pathway potential ( $p < 0.05$ ) were found to be independent predictors of successful outcome, whereas the atrioventricular interval, atrioventricular amplitude ratio, stability of local electrogram, and presence of continuous electrical activity were not. A QRS-V interval of  $\leq +10$  ms identified successful sites with a sensitivity of 98%, but the positive predictive accuracy was only 11%. Even a QRS-V interval of  $\leq 20$  ms resulted in only a 24% probability of success with a sensitivity of just 18%. Combining the QRS-V interval with the presence of a possible accessory pathway potential greatly reduced the sensitivity at all cut off values, but failed to increase positive predictive accuracy above 25%. There were no significant differences in electrogram characteristics between the successful sites and the sites at which conduction of the accessory pathway was interrupted transiently. There were 57 sites (nine successful, 48 failed) at which ablation was guided by retrograde mapping, but none of the local electrogram characteristics analysed emerged as independent predictors of successful pathway ablation.

**Conclusion**—Local electrogram characteristics used to guide radiofrequency catheter ablation are all associated with a

low positive predictive accuracy, which significantly contributes to duration of the operation. It is unlikely that this problem will be resolved solely by modification of the mapping techniques. It could require advances in catheter technology and power sources to enable larger tissue lesions to be delivered more reliably than is possible with the equipment in current use.

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Radiofrequency catheter ablation has rapidly gained acceptance as a first line treatment for symptomatic arrhythmias related to accessory atrioventricular pathways, with several groups reporting primary success rates of 90% or better and excellent short-term safety records.<sup>1-4</sup> A limitation of the technique at present is the unpredictable and often lengthy duration, of the operation which averaged between 2.2 and 8.3 hours in the four largest series.<sup>1-4</sup> This was principally due to the variable number of sites at which lesions had to be delivered before accessory pathway conduction was abolished; the shortest mean duration of operation was achieved by Calkins *et al* with an abbreviated protocol, but even they required up to 39 lesions for success with 15%-20% of the cases lasting for over four hours.<sup>3</sup> Although these results show the necessity for precise location of the pathway, only two groups have reported in detail the results of mapping before attempted radiofrequency catheter ablation to establish optimum electrogram criteria for the identification of appropriate target sites.<sup>5,6</sup> These studies are difficult to interpret because, whereas all successful target sites were analysed, a significant proportion of unsuccessful target sites (including sites at which accessory pathway conduction was blocked transiently) were excluded from the analysis. This would have had the effect of exaggerating both the differences between successful and unsuccessful sites and also the predictive value of electrogram criteria for the identification of successful sites. To avoid this limitation, we have examined the relation between local electrogram characteristics and outcome after radiofrequency current delivery for all attempted sites in a consecutive series of patients undergoing catheter ablation of accessory pathways, to find which if any criteria would be useful in identifying successful target sites.

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## Patients and methods

### PATIENTS

Between January 1991 and May 1992, 75 patients (42 males, 33 females; age six to 67 years) with 76 accessory pathways underwent attempted radiofrequency catheter ablation. There were 64 patients with Wolff-Parkinson-White syndrome and 11 patients with concealed accessory pathways. Pathway locations were: left free wall 37, posteroseptal 32, right anteroseptal or lateral five, and right free wall two. The indication for ablation was drug refractory atrioventricular reentrant tachycardia (60 cases) and rapid pre-excited atrial fibrillation (23 cases). Three patients had previously undergone unsuccessful surgical division of the pathway and two patients were referred from other centres after failed attempts at radiofrequency ablation.

### ABLATION TECHNIQUES

Patients were sedated with intravenous diazepam and diamorphine; procedures on children and adolescents were conducted under general anaesthesia. A 100 U/kg bolus of heparin was given for all left heart procedures. Mapping and ablation were performed with a 7F deflectable catheter with a 4 mm tip and 2.5 mm interelectrode spacing (Polaris; Mansfield-Webster). After the first 10 cases in the series, a single catheter technique was adopted and additional atrial or ventricular wires were introduced solely for the purposes of pacing.

For left free wall pathways, the Polaris catheter was introduced through the femoral artery retrogradely across the aortic valve and positioned on the mitral annulus; in three cases, satisfactory catheter manipulation proved impossible through the transaortic route and the Polaris catheter was introduced trans-septally into the left atrium. Right lateral and anteroseptal pathways were approached from the femoral vein with the catheter positioned on the tricuspid annulus. Posteroseptal pathways were either approached through the retrograde transaortic route with the catheter positioned on the medial aspect of the mitral annulus, or through the femoral vein with the catheter positioned on the tricuspid annulus or within the proximal coronary sinus; in eight cases, a bipolar electrode configuration was used with current delivered between catheters positioned on either side of the septum.

Bipolar electrograms were recorded from the distal pair of electrodes, filtered at 30–500 Hz, amplified at gains of 20–80 mm/mV, and printed at paper speeds of 100–200 mm/s together with three or four surface electrocardiographic leads on a multichannel ink jet recorder (Mingograf 7, Siemens-Elema). In patients with stable pre-excitation, antegrade mapping was performed during sinus rhythm or atrial pacing. Target sites for ablation were identified by the presence of discrete atrial and ventricular electrograms in the same recording, early local ventricular activation relative to onset of the delta wave on the surface electrocardiogram and continuous atri-

oventricular electrical activity or a possible accessory pathway potential. Concealed pathways were located during right ventricular pacing by the presence of discrete ventricular and atrial potentials, early retrograde atrial activation, and continuous ventriculoatrial electrical activity. Patients with intermittent pre-excitation but stable retrograde accessory pathway conduction were also mapped during right ventricular pacing.

Radiofrequency current was supplied by a 500 kHz generator (HAT200S, Dr Osypka GmbH) at constant present electrical power (typically 30–50 W). A large indifferent patch electrode was positioned over the patient's left thigh or shoulder. The generator was interfaced with a personal computer that ran dedicated software for real time display and recording of power output, cumulative energy and system impedance during each application. Radiofrequency current was delivered for up to 60 seconds at each site but the pulse was normally interrupted at 10 seconds if accessory pathway conduction failed to block within this time; however, if lesions at several apparently favourable sites had proved ineffective, current was continued for up to 30 seconds before interruption.

Once conduction of an accessory pathway had been abolished, patients were observed for at least 30 minutes (left sided pathways) or 45 minutes (right sided pathways) in the catheter laboratory. After this time all electrodes were removed. If conduction resumed within this period, further attempts at ablation were made. A 12 lead electrocardiogram was recorded on return to the ward and the next morning. Patients were normally discharged from hospital within 24 hours and returned for a repeat electrophysiological study two to six weeks later.

### ELECTROGRAM ANALYSIS

Electrograms recorded at all sites of attempted unipolar radiofrequency ablation immediately before current delivery were analysed independently by two observers in blinded fashion; in the event of discrepancies, the electrograms were reanalysed by a separate observer and a consensus reached. For sites at which ablation was guided by antegrade mapping certain electrogram criteria were examined: (a) local atrioventricular interval (A-V); (b) interval from the onset of the earliest delta wave on the surface electrocardiogram to local ventricular activation (QRS-V); (c) the amplitude ratio of the atrial and ventricular deflections of the local electrogram (A:V ratio); (d) the presence of continuous electrical activity—that is, no isoelectric segment between the atrial and ventricular deflections; (e) the presence of a possible accessory pathway potential—that is, any deflection preceding the onset of the QRS complex and distinguishable from the atrial and ventricular components of the local electrogram (fig 1); (f) stability of atrial electrogram, calculated as the ratio of the smallest to the largest amplitude of atrial deflection in five consecutive cycles immediately preceding

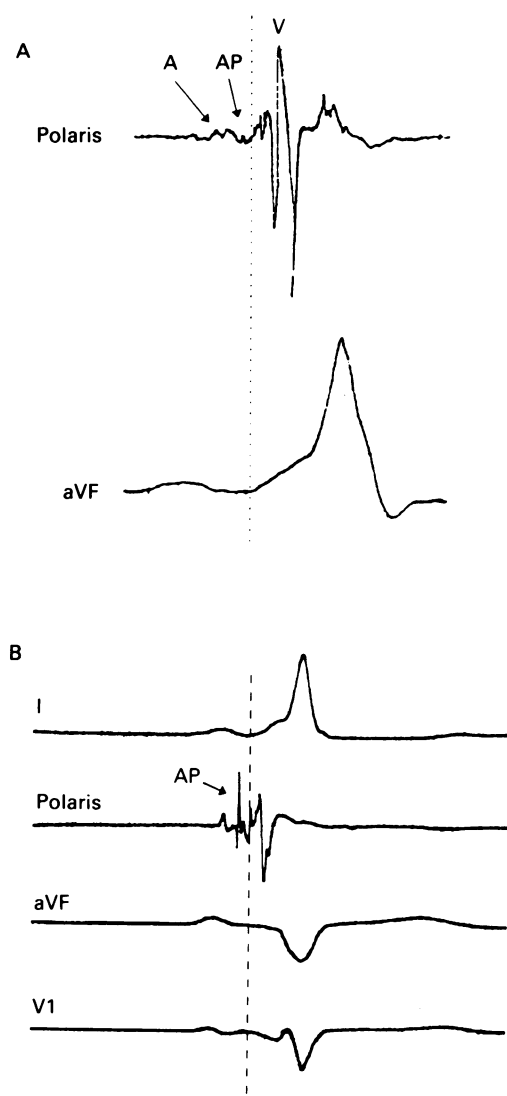


Figure 1 Representative examples of possible accessory pathway potentials (APs) recorded through the distal poles of the Polaris catheter. Accessory pathway activation is usually detected as a discrete, low amplitude deflection preceding the onset of the delta wave on the surface electrocardiogram but distinct from local atrial and ventricular electrograms, as in example (A) from a patient with a left free wall pathway. Recording from the tricuspid annulus, much more prominent deflections are occasionally found as in example (B) from a patient with a right posteroseptal pathway. Delivery of lesions at both these sites abolished pathway conduction permanently.

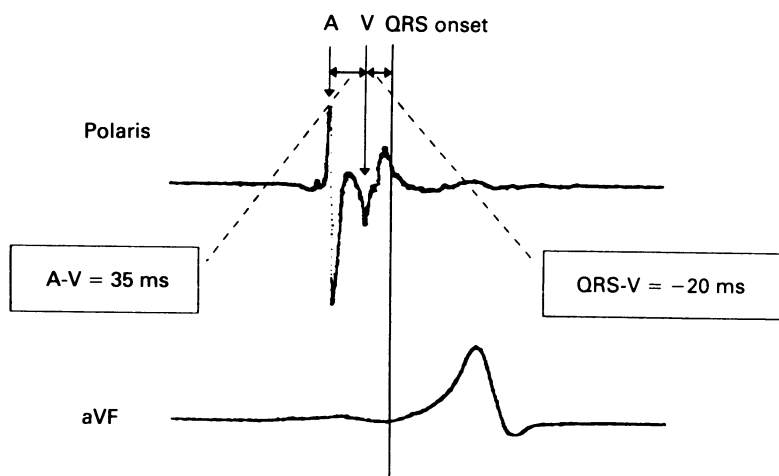


Figure 2 Electrogram recording taken from the Polaris catheter positioned on the atrioventricular ring together with lead aVF to illustrate the derivation of the time intervals used in the study: the local atrioventricular interval (A-V) and the interval from onset of the QRS complex on the surface electrocardiogram to local ventricular activation (QRS-V). Local ventricular activation (V) is measured from the peak of the first rapid deflection, and this case preceded the onset of the QRS complex giving a negative value for the QRS-V interval.

current delivery; (g) stability, of the ventricular electrogram, computed in the same way as stability of the atrial electrogram. As many electrograms contained complex fractionated signals, local activation was always measured taking the peak of the first rapid deflection whether or not this was considered to be the intrinsic deflection (fig 2). No attempt was made to verify possible accessory pathway potentials by programmed stimulation. For sites at which ablation was guided by retrograde mapping another set of criteria were examined: (a) local ventriculoatrial interval (V-A); (b) the interval from stimulus to local atrial activation ( $S_1$ -A); (c) the amplitude ratio of the atrial and ventricular components (A:V ratio); (d) the presence of continuous ventriculoatrial electrical activity; (e) stability of the atrial electrogram (f) stability of the ventricular electrogram.

Successful sites were those at which accessory pathway conduction was abolished and remained absent throughout the observation period of 30–45 minutes. Unsuccessful sites were subdivided into those at which current delivery had no effect and those at which accessory pathway conduction was blocked temporarily but resumed during the observation period. Figures 3 and 4 show representative examples of successful sites during antegrade and retrograde mapping.

#### STATISTICAL ANALYSIS

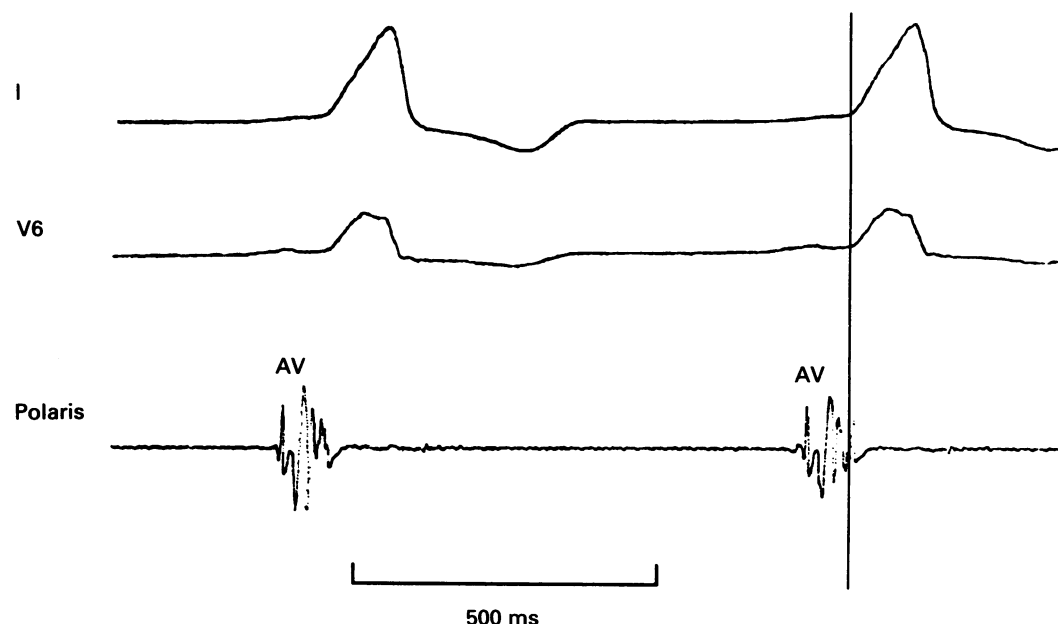
Data are expressed as mean (SD) unless otherwise stated. Continuous variables were compared for successful and unsuccessful sites by Student's *t* test and  $\chi^2$  analysis. The significance of individual predictive variables was initially tested by univariate logistic regression. Multivariate stepwise logistic regression was then performed to find the most powerful independent predictors of outcome. Probability values of  $< 0.05$  were considered significant. Sensitivity, specificity, and positive and negative predictive accuracy were calculated by standard formulas.

#### Results

The first attempt at ablation was successful in 65 of 76 pathways and a second attempt in 7 of 8 pathways, giving an overall success rate of 72 out of 76 (95%). Median duration of operation including observation periods was 135 (range 35–360) minutes and screening time was 29 (range three to 187) minutes. The number of lesions delivered varied from one to 51 (median nine) per patient. In operations lasting  $< 4$  hours the median number of lesions was six (range one–26) whereas for operations lasting  $> 4$  hours (about 20% of cases) the median number of lesions was 31 (range six to 51).

Sixteen cases were excluded from the electrogram analysis either because catheters with a 5 mm interelectrode spacing were used or because ablation was accomplished with double catheter configurations. Electrograms from all 568 sites of attempted ablation in the remaining 60 patients were analysed.

**Figure 3** Electrogram recording taken during sinus rhythm at a successful ablation site of a right anterolateral accessory pathway together with leads I and V<sub>6</sub> showing atrial (A) and ventricular (V) deflections that are continuous with ventricular activation preceding onset of the QRS complex.



#### ABLATION SITES GUIDED BY ANTEGRADE MAPPING

A total of 511 sites at which radiofrequency from 51 patients with pre-excitation current was delivered were analysed. There were 49 successful sites and 462 unsuccessful sites, including 61 at which accessory pathway conduction was blocked transiently. Table 1 shows the local electrogram characteristics. Comparing successful sites with all unsuccessful sites, the only significant differences were in the QRS-V interval ( $-8(13)$  v  $+3(14)$  ms;  $p < 0.001$ ), and the proportion exhibiting possible accessory pathway potentials (49% v 24%;  $p < 0.001$ ) or continuous atrioventricular electrical activity (73% v 55%;  $p < 0.05$ ). There were, however, no significant differences between the 49 successful sites and 61 sites at which accessory pathway conduction was interrupted temporarily (table 2). The time from the start of the current to loss of pre-excitation was significantly shorter at the successful sites ( $6(5)$  v  $10(6)$ ;  $p < 0.0001$ ), but there was considerable overlap

between the groups (fig 5). Based on univariate analysis, electrogram characteristics that were predictive of a successful outcome were QRS-V interval ( $p < 0.0001$ ), the presence of a possible accessory pathway potential ( $p < 0.0001$ ), and continuous electrical activity ( $p < 0.05$ ). With stepwise multivariate logistic regression, only the QRS-V interval ( $p = 0.0002$ ) and possible accessory pathway potentials ( $p = 0.029$ ) remained as independent predictors of success. The predictive value of these two variables in differentiating successful and unsuccessful sites was quantified with standard equations to calculate sensitivity, specificity, and positive and negative predictive accuracy. Figure 6 shows the results. All electrograms with a QRS-V interval of  $\leq 10$  ms identified successful sites with a sensitivity of 98% but the positive predictive accuracy (that is, the probability of success) was only 11%. More stringent cutoffs for the QRS-V interval only gave a modest increase in positive predictive accuracy at the expense of progressive reductions in sensitivity: even

**Figure 4** Electrogram recording taken at a successful ablation site of a concealed left posteroseptal accessory pathway together with leads I and aVF, showing discrete ventricular (V) and atrial (A) deflections that are virtually fused during right ventricular pacing (retrograde conduction through the pathway) but are readily distinguishable during sinus rhythm.

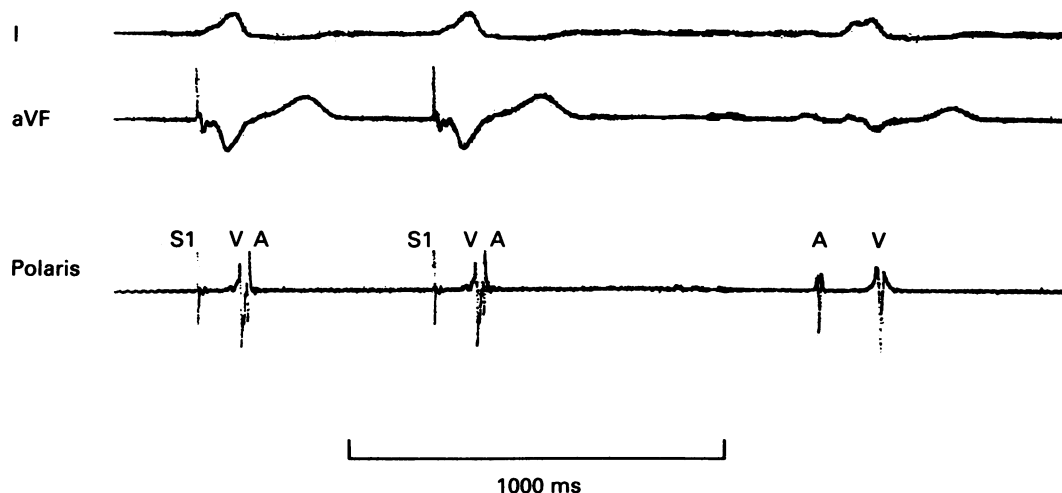


Table 1 Comparison of electrogram characteristics at successful and failed sites during ablation guided by antegrade mapping

Variable	Failed sites (n = 462)	Successful sites (n = 49)	p Value
A-V (ms)	41 (15)	37 (14)	0.061
QRS-V (ms)	+ 3 (14)	8 (13)	<0.001
A:V ratio	1.22 (2.20)	1.59(3.40)	NS
AP	24%	49%	<0.001
Continuous	55%	73%	0.049
A stability	0.75 (0.19)	0.80 (0.20)	NS
V stability	0.81 (0.15)	0.77 (0.17)	NS

A-V, local atrioventricular interval; QRS-V, interval from onset of earliest delta wave (surface electrocardiogram) to local ventricular activation; A:V ratio, ratio of maximum amplitudes of the atrial and ventricular components of the local electrogram; AP, presence of a possible accessory pathway potential in the local electrogram; Continuous, presence of continuous atrioventricular electrical activity; A stability, stability of the atrial electrogram; V stability, stability of the ventricular electrogram.

Table 2 Comparison of electrogram characteristics at successful sites and sites at which accessory pathway conduction was blocked transiently during ablation guided by antegrade mapping

Variable	Transient block sites n = 61)	Permanent block sites (n = 49)	p Value
A-V (ms)	34 (14)	37 (14)	NS
QRS-V (ms)	-5 (13)	-8 (13)	NS
A:V ratio	1.09 (1.04)	1.59 (3.40)	NS
AP	36%	49%	NS
Continuous	68%	73%	NS
A stability	0.74 (0.20)	0.80 (0.20)	NS
V stability	0.83 (0.13)	0.77 (0.17)	NS

Abbreviations as for table 1.

with QRS-V intervals of  $\leq -20$  ms (representing extremely early local ventricular activation), the predicted probability of success would have been 24% and only 18% of successful target sites would have been detected. Similarly, the combination of a possible accessory pathway potential with the QRS-V interval greatly reduced sensitivity at all cut off values but only increased positive predictive accuracy to around 20%-25%. We also compared the predictive value of the QRS-V interval for the 315 left sided sites with 196 right sided sites (fig 7). A QRS-V interval of  $\leq 0$  ms would have identified all successful sites for right sided pathways but would have failed to detect 16% of successful left sided sites; to achieve close to 100% sensitivity for detection of left sided sites would require a cut-off of  $\leq +10$  ms. There was, however, little difference in positive predictive accuracy for left or right sided sites.

Figure 5 Time from start of current to loss of pre-excitation for all sites at which accessory pathway conduction was blocked transiently (n = 61) or permanently (n = 49) during ablation guided by antegrade mapping. Mean values for the two groups are represented as horizontal bars. Although the time to block was significantly shorter at the successful sites (p < 0.0001), there was considerable overlap between the two groups.

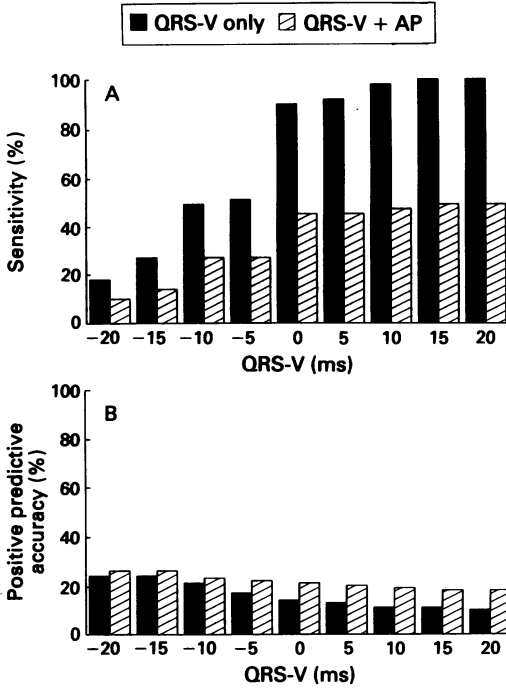
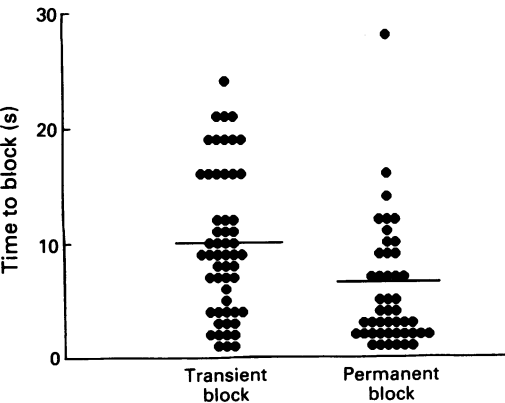


Figure 6 Sensitivity (A) and positive predictive accuracy (B) of the QRS-V interval alone (solid bars) or in combination with a possible accessory pathway potential (hatched bars) for the identification of successful ablation sites (n = 49) from among the total population of attempted sites (n = 511) guided by antegrade mapping.

ABLATION SITES GUIDED BY RETROGRADE MAPPING

Electrograms from 57 sites from nine patients were analysed. There were nine successful sites and 48 unsuccessful sites including six at which pathway conduction was blocked temporarily. There were no significant differences in electrogram characteristics between successful and failed sites (table 3).

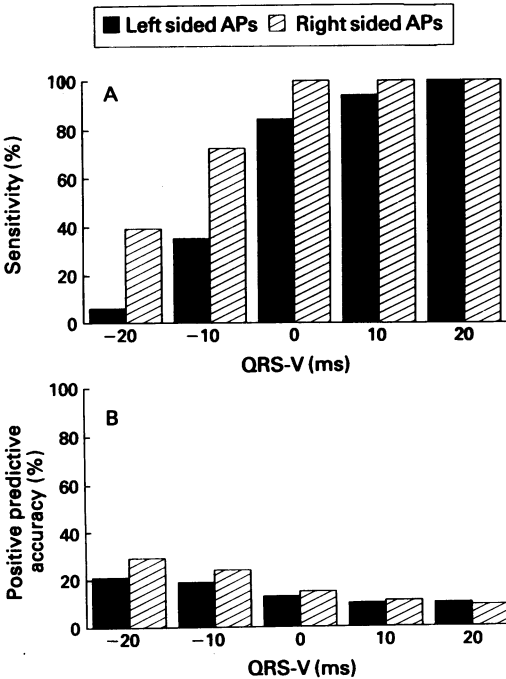


Figure 7 Comparison of the sensitivity (A) and positive predictive accuracy (B) of the QRS-V interval for identification of successful sites for left sided pathways (solid bars) and right sided pathways (hatched bars).

**Table 3** Comparison of electrogram characteristics at successful and failed sites during ablation guided by retrograde mapping

Variable	Failed sites (n = 48)	Successful sites (n = 9)	p Value
V-A (ms)	39 (17)	33 (13)	NS
S <sub>1</sub> -A (ms)	147 (29)	138 (32)	NS
A:V ratio	0.62 (0.64)	0.41 (0.31)	NS
Continuous	78%	87%	NS
A stability	0.78 (0.19)	0.87 (0.11)	NS
V stability	0.80 (0.18)	0.88 (0.10)	NS

Abbreviations as for table 1 and; V-A local ventriculoatrial interval;  
S<sub>1</sub>, interval from stimulus to local atrial activation;  
Continuous, presence of continuous ventriculoatrial electrical activity.

Furthermore, univariate analysis failed to identify any electrogram criteria as predictors of successful sites.

### Discussion

This study has shown that, during ablation guided by antegrade mapping, the only local electrogram characteristics that are independently predictive of successful target sites are the interval from the onset of the delta wave to local ventricular activation (QRS-V) and the presence of a possible accessory pathway potential. Delivery of lesions at sites where the QRS-V interval is > 0 ms for right sided pathways or + 10 ms for left sided pathways is extremely unlikely to abolish conduction. These criteria, however, only give a positive predictive accuracy of around 10%—that is, only one in 10 of apparently suitable sites would prove successful. The probability of success can be improved to around 20%–25% either by setting a more stringent cut off for the QRS-V interval or by requiring the additional presence of a possible accessory pathway potential, but in each case this would be achieved at the expense of a large reduction in the sensitivity with which successful sites were detected. Like other groups, we have not found the presence of an accessory pathway potential at target sites to be an essential requirement for successful ablation.<sup>25</sup> These signals could not be recorded at nearly half of the successful sites, possibly because, the orientations of the ablation catheter were wrong relative to the bypass tract, or the pathway potential may fuse totally with the local atrial or ventricular electrograms.<sup>7</sup>

A subsidiary finding was that successful sites are indistinguishable on the basis of electrogram characteristics from unsuccessful sites at which accessory pathway conduction is interrupted temporarily. Furthermore, these sites cannot be reliably differentiated according to the time from the start of the current to loss of preexcitation, although collectively this was significantly shorter at the successful sites. We were unable to identify any independent predictors of successful sites during ablation of concealed pathways guided by retrograde mapping, but this may have been a reflection of the small number of cases in the series.

The poor specificity of local electrogram criteria in detection of appropriate target sites could have several explanations. Probably the

most important factor is that radiofrequency current produces very discrete myocardial lesions just a few mm across;<sup>8</sup> favourable electrograms may be recorded from catheter positions in the vicinity of the pathway that are still not close enough for success. Furthermore, even if the catheter is optimally positioned, resistive heating and lesion generation may not result if there is inadequate contact pressure between electrode and tissue.<sup>8</sup> Another possible explanation for failure at apparently favourable sites is microdisplacement of the catheter during delivery of the current, either spontaneously or as a result of induced extrasystoles, although this might be expected to produce an obvious change in electrogram morphology immediately afterwards. This was seldom found in practice.

### PREVIOUS STUDIES

Several groups have now presented their clinical experience with radiofrequency catheter ablation in large series of patients with accessory atrioventricular pathways with comparable mapping and ablation techniques to those used in this study.<sup>2-4</sup> Our results closely resemble those of the other groups in terms of overall success rate (86%–94%), median number of lesions required for each case (eight to nine) and duration of operation (2.3–4.3 hours). The remarkable similarity in the number of attempted ablation sites required for success in these different series suggests that the problem with poor specificity of mapping criteria has been found universally.

We are only aware of two other studies that have formally examined the predictive value of local electrogram characteristics in identifying appropriate sites for delivery of lesions.<sup>5,6</sup> Calkins *et al* analysed local electrograms of successful catheter ablation of accessory pathways from 438 attempted sites in 132 patients.<sup>5</sup> They also found that the time of local ventricular activation relative to the start of the QRS complex and the presence of possible accessory pathway potentials are independent predictors of successful outcome during ablation of manifest pathways but, by contrast with our study, electrogram stability was shown to be an important criterion for identification of appropriate target sites as well. An all or nothing definition of electrogram stability was used, based on < 10% fluctuation of the atrioventricular amplitude ratio. The combination of these three electrogram criteria yielded a positive predictive accuracy (that is a probability of success) of 57% which was much higher than we were able to obtain. Their apparently very dissimilar results, however, might be largely accounted for by differences in data selection. All sites at which pathway conduction was temporarily blocked were excluded from the analysis, although our results have shown that these are indistinguishable from successful sites on all electrogram criteria; this would have had the effect of exaggerating differences in electrogram characteristics between suc-

cessful and unsuccessful sites. Furthermore, only successful cases were studied and whereas all of the successful sites were analysed, over half of the unsuccessful sites were excluded; this would tend to spuriously increase the figures for positive predictive accuracy because only false positives were being discarded from the analysis. In fact the mean number of attempted sites for each case was similar in the two studies (7.2 v 9.5). We believe that our approach of analysing all attempted sites from both successful and unsuccessful cases has greater scientific validity and is more relevant to clinical practise.

Silka *et al* analysed electrograms from 326 sites during ablation of 107 accessory pathways.<sup>6</sup> By complete contrast, the local atrioventricular interval was found to be the most powerful independent predictor of successful sites: a cutoff value of 50 ms for the atrioventricular interval gave a positive predictive accuracy of 81% with a sensitivity of 88%. A QRS-V interval of < 0 ms achieved a positive predictive accuracy of 43% with a sensitivity of 74%. Once again, these apparently impressive numbers are probably due to selective inclusion of data. Electrograms from all 93 successful sites were analysed but only from 233 failed sites. No indication is given of the total number of attempted sites, nor is it clear how electrograms were chosen for inclusion in the analysis except that, as in the study of Calkins *et al*,<sup>5</sup> sites at which accessory pathway conduction was interrupted transiently were specifically excluded.

#### CLINICAL IMPLICATIONS

Although the success rate with radiofrequency ablation of accessory pathways is around 90%, a significant limitation is that some cases require extremely lengthy operations, occasionally even exceeding five hours, with the associated problem of additional radiation exposure. Lack of operator experience and difficulty with catheter manipulation and stabilisation certainly contribute to procedure duration,<sup>9</sup> but another important factor is the variable number of sites at which lesions have to be delivered to achieve success. In our series, the median number of lesions required for each case was six for operations lasting < four hours but three for operations lasting > four hours. Reducing the number of attempted target sites would therefore seem to be a logical approach to improving the efficiency of the technique in clinical practice. As previously discussed, this problem is largely due to the poor specificity of electrogram criteria for identification of appropriate sites. One solution might be to verify all suspected accessory pathway potentials by programmed stimulation and only deliver lesions where definite pathway activation is detected.<sup>7</sup> Whether this

would shorten the operations is doubtful because the validation techniques themselves are time consuming and many potentially successful sites without pathway potentials would be rejected. Jackman *et al* recorded verified pathway potentials at 92% of effective sites and achieved success with a median of three lesions per case as compared with nine lesions per case in our series, but their operations lasted about three times as long with an average duration of 8.3 hours.<sup>1</sup>

The predictive value of existing mapping criteria could also be improved by technological advances that increased lesion size or the reliability with which lesions are generated. The use of catheters equipped with thermistors for monitoring tip temperature helps to distinguish (retrospectively) between incorrect positioning and inadequate tissue heating at unsuccessful sites with apparently favourable electrogram characteristics,<sup>10</sup> but it is difficult to see how this would facilitate recognition of successful sites in the first place. A solution to the problem may come from the future development of alternative power sources such as microwave energy that are capable of generating larger myocardial lesions than radiofrequency current and are less dependent on adequate contact pressure between electrode and tissue.<sup>11</sup>

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